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TITLE – Description of an Augmented LM and Comparison with the AAP Shelter/Taxi Approach (U)

TM – 66-1013-13

FILING CASE NO(S) – 103-3

DATE – October 19, 1966

AUTHOR(S) – J. E. Waldo

FILING SUBJECT(S) – (ASSIGNED BY AUTHOR(S)) –
Apollo Spacecraft
Augmented LM
LM Shelter/Taxi
Saturn Apollo Applications

ABSTRACT

An Augmented LM approach to provide increased LM staytime and payload is described. This approach is based on minimum modifications to the LM and CSM, and assumes that confidence from early Apollo landings and the availability of Apollo margins will permit evolutionary growth in capability.

The results indicate that a nominal 7-day staytime and descent and return payloads of approximately 500 lbs may be feasible without uprating of the Saturn V or the LM descent propulsion.

There are several additional considerations affecting the sources and limitations of potential improvements for preserving a minimum modification approach. Subjects recommended for further study are ΔV requirements, projected launch vehicle and spacecraft propulsion capability, and specific structural limitations of the SLA/LM interface, CM chute, CM return payload, LM landing gear, and LM descent stage structure.

A comparison with the current AAP Shelter/Taxi approach shows that both approaches have advantages. These are related, basically, to a greater Shelter staytime, descent payload, and payload volume and the ALM relative simplicity, single Saturn V launch, and return payload. The ALM will not provide LSSM-type mobility; on the other hand, it can visit twice the lunar sites and will return twice the payload on a per-Saturn V basis. Other likely advantages are higher probability of mission success and crew safety, greater accessibility, lower development risk, and a reduced near-term NASA commitment.

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SUBJECT: Description of an Augmented LM and Comparison with the AAP Shelter/Taxi Approach - Case 103-3 (U)

DATE: October 19, 1966

FROM: J. E. Waldo

TM-66-1013-13

TECHNICAL MEMORANDUM

1.0 INTRODUCTION

The Augmented LM is a concept for AAP lunar surface missions, as an alternative to the LM Shelter/Taxi approach. The ALM is considered to be an uprated LM that provides, basically, single Saturn V missions with staytimes and payloads greater than Apollo, though less than the Shelter/Taxi combination.

There are several possible approaches to implementing this concept. Fundamentally, these approaches are of two types: creation of a new LM derivative, as in the Shelter/Taxi approach, and uprating of the LM to provide evolutionary growth in staytime and payload. This memorandum considers an Augmented LM of the second type, based on the assumption that confidence from early Apollo landings and the availability of Apollo margins will permit this evolutionary growth.

This memorandum has two purposes:

1) To describe an Augmented LM approach, based on minimum changes to the LM, and

2) To compare this approach with the present Shelter/Taxi approach.

It should be noted that the differences and arguments presented are intended to be technical; though they unavoidably concern the scientific and programmatic aspects of both approaches. The intent is to point out the differences in the approaches and their implications as they appear at this time, rather than to attempt to evaluate, for example, the scientific merit of two discrete sites vs one site or the usefulness of a 1500 lb. roving vehicle payload.

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It also should be noted that the two approaches have not been studied to equal depth. The Shelter/Taxi has been the primary AAP mode for lunar surface exploration for over one and one-half years; the Augmented LM was only recently suggested and is little more than a concept. Thus, for the Shelter/Taxi we have fairly well defined spacecraft and supporting data and, for the Augmented LM, an arbitrarily defined approach.

A second major difference is that the Augmented LM may require uprating of the LM descent propulsion and the Shelter/Taxi studies have not assumed this uprating. A comparison of Augmented LM vs Shelter/Taxi could, and possibly should, extend to Augmented Shelter/Augmented Taxi. This suggests the comparison of a range of LM derivatives (e.g., minimum Augmented LM, Augmented LM, Shelter/Taxi, Augmented Shelter/Taxi, and Augmented LM Truck). For the present, we will consider the Augmented LM and the relatively well-defined Shelter/Taxi, recognizing that we are comparing a flexible, loosely constrained concept with one that has been optimized for a given set of ground rules.

It is first necessary to describe an Augmented LM. This is done, based on assumptions concerning the ALM concept and the AAP it would fit best. It is recognized that spacecraft weight, both the LM and the associated CSM, provide the most significant constraint. These weights are estimated and approaches selected on the basis of tradeoffs and assumptions, as detailed in the Appendices.

A note on the Grumman ALM study

Since the time this material was prepared the Grumman ALM study for MSC has been reported with some important differences, chiefly, in separation weight and the extent of modification. Grumman was directed to use an uprated Saturn V injection capability of 103,000 lbs. and an increased LM separation weight of 39,000 lbs. This separation weight immediately dictates two significant, and possibly unnecessary, constraints on the ALM approach:

1) Descent propulsion improvement,

2) Descent stage structural beef-up.

Both are long lead time items. In addition, the definite requirement for beef-up of the descent stage structure effectively places the ALM in the Shelter/Taxi class of LM derivatives by prohibiting post-production modification of an Apollo LM to the Augmented LM configuration.

2.0 AUGMENTED LM APPROACH

A description of the ALM approach based on minimum modifications requires consideration of the desired increased capability, the sources of improvement, and the limitations on these improvements.

The increased capability is primarily a weight consideration, e.g., increases in spacecraft weight, descent payload, and return payload. The sources of improvement are in operational changes and Apollo margins, e.g., reductions in spacecraft weight and ΔV requirements, and improved Saturn V and spacecraft propulsion capability. The limitations on these improvements are dictated by the minimum modification approach, e.g., Saturn V and spacecraft propulsion uprating, and structural limits of the spacecraft and SLA.

In the following sections the weight increase is estimated for the ALM and the associated CSM for an ALM staytime of seven days. Combinations of descent and return payloads are added to these weights and the resulting values are reflected back through an Apollo profile mission to estimate propellant and Saturn V requirements. The effect of the different spacecraft inert and payload weight changes on the propellant and launch vehicle requirements is shown in Figure 1. The related sensitivities, based on Apollo ΔV's, and the resulting weights are detailed in Appendix C (CONFIDENTIAL). Sources of improvement and the probable sources of limitations for a minimum modification approach are identified in a final section, with examples of the type of improvements that are expected.

EFFECT OF SPACECRAFT INERT AND PAYLOAD WEIGHT CHANGES
ON PROPELLANT AND LAUNCH VEHICLE REQUIREMENTS

	CSM Inert A/S Payload	CSM Inert	CSM Inert	S-IVB	SaV
		SM Propellant for Tel	SM Propellant for TLI & LOI		
A/S Inert	A/S Inert	A/S Inert	A/S Inert		
A/S Payload	A/S Propellant	A/S Propellant	A/S Propellant		
	D/S Inert D/S Payload	D/S Inert D/S Payload D/S Propellant	D/S Inert D/S Payload D/S Propellant		

FIGURE 1

2.1 Augmented LM

Modifications to the LM for the Augmented LM mission are based on the following assumptions:

- 7-day staytime
- Minimum modifications

    Simple add-ons to existing LM subsystems
    Modify subsystems for clear weight advantage only

- Nominal Apollo mission profile
- Apollo LM subsystems are suitable for a 7-day staytime
- Electrical energy based on Apollo power levels
- Two EVA per day

Software changes are expected because of c.g. and inertia differences; however there are essentially no changes in weight for stabilization and control, navigation and guidance, and communications. It is assumed that landing gear and reaction control changes are possible, based on the results of early Apollo landings, but that these changes will not increase the LM weight. Minor changes are assumed for structure, additional crew provisions, instrumentation, and controls and displays.

The major changes, in terms of weight and modification, are in environmental control and electrical power. Additional ECS expendables for crew use (LiOH, oxygen, and water) are fixed by staytime, and represent nearly half of the total weight increase. ECS thermal control can be increased by carrying additional water in the descent stage or by adding a radiator to the glycol system. The radiator approach is lighter overall, but requires more extensive modification and increases the ascent stage weight. The heavier but simpler approach of adding water tanks to the descent stage was selected for this study.

Electrical power can be increased by add-on batteries, add-on solar cell array, or fuel cells. RTG's were not considered because of weight, availability, and no requirement for waste heat. The solar cell array approach was selected on the basis of weight and simplicity.

The resulting weight changes are shown below.

	Δ Ascent Stage Wt.	Δ Descent Stage Wt.
Structure	34	0
Crew Provisions	0	91
ECS (except thermal control)	0	452
ECS thermal control	0	446
EPS	0	-18
Total	34 lb.	971 lb.

The following table shows the total weight change of the selected approach, using add-on ECS (water) and add-on EPS (solar cell), as opposed to combinations of modified ECS (radiator) and modified EPS (fuel cells). Separation weight is estimated as 2 x D/S inert and 4 x A/S inert stage weight.

ECS	EPS	Δ Ascent Stage Wt.	Δ Descent Stage Wt.	Δ Separation Weight
Water	Solar Cell	34	971	2078
Radiator	Solar Cell	128	485	1482
Water	Fuel Cells	34	1101	2338
Radiator	Fuel Cells	128	615	1742

2.2 CSM for Augmented LM

Modifications to the CSM for the Augmented LM mission are based on the same assumptions as used before for the Augmented LM estimate. The total CSM mission time is assumed to have an upper bound of 16.7 days (400 hours); based on 110 hours translunar and transearth times, 170 hours of CSM solo operations in lunar orbit, and 11 hours miscellaneous. 110 hours translunar and transearth times were chosed to reduce ΔV requirements and reentry velocity.

The Block II subsystems are assumed to be suitable for a 16.7 day mission. On this basis, no specific subsystem modifications appear to be required beyond the provision of expendables. This requires the addition of one Block II hydrogen tank and one Block II oxygen tank. RCS may be an exception. Because of Apollo indecision on the suitability of RCS quantities, it was first assumed for this study that the current propellant quantities are sufficient for Apollo and that increased requirements for the Augmented LM mission will exceed the present RCS tankage. It was found, however, that the additional requirement was approximately 68 lbs., including penalties for 1-quad-out and MSFN failure. This increase, as opposed to the 790 lb. Block II usable quantity, does not appear to justify either an extensive analysis or an excessive modification and weight penalty for the purposes of this study.

The total additional weight for expendables beyond Block II usable quantities are shown below.

	Δ Wt.	Tankage	Total
RCS	68	-	68
Oxygen (ECS and EPS)	237	82	319
Hydrogen	36	164	200
Food & LiOH	neglig.		-
Total			587 lbs.

2.3 ALM separation weight and total injected weight

The effects of spacecraft inert and payload weight changes on propellant and launch vehicle requirements are estimated in Appendix C (CONFIDENTIAL). These estimates are based on Apollo control weights, propellant mass ratios from the Apollo ΔV budget, and the calculated increased inert weights for the LM ascent stage (34 lb.), LM descent stage (971 lb.), and CSM (590 lb.). The table below shows the Saturn V injected weight, the Augmented LM separation weight, and the descent propellant required for various combinations of descent and return payloads.

Descent Payload	Return Payload	Descent Propellant	ALM Separation Wt.	Total Injected Wt.*
250	80	18175	34331	94926
250	250	18360	34680	95494
250	500	18631	35192	96329
500	80	18456	34862	95676
500	250	18641	35211	96244
500	500	18912	35723	97079
1000	80	19019	35925	97176
1000	250	19204	36274	97744
1000	500	19475	36786	98579

Ascent stage and SM propellant quantities and current Saturn V injection capability appear to be adequate. However, in all cases, the requirements exceed descent propellant quantities. Usable tankage capacity is exceeded by 800 to 2100 lb. This does not include additional tankage or related structure modification weight, and no consideration or allowance for descent engine modification.

2.4 Apollo Margins and Mission Performance

The ALM evolutionary approach assumes that confidence from early Apollo landings and the availability of Apollo margins will permit this growth. The possible sources of improvement are in operational changes and Apollo margins, such as increased spacecraft propulsion capability without deliberate uprating. Potential improvements in performance and accessibility through operational changes are listed below by mission phase.

Launch

- Reduced opportunity

Translunar Injection

- Non-free return
- Longer flight time
- Reduce midcourse correction

*Includes SLA (3800 lbs.).

Descent

Reduced orbit altitude

Reduced hover time

Longer Hohmann

Lunar Surface

Reduce anytime abort

Ascent

Reduce plane change

Direct ascent

Reduce rescue

Transearth Injection

Longer flight time

Increase recovery area

Specific limitations on improvements are dictated by the minimum modification approach. Items to be considered, several of which are structural limits, are:

CM chute load

LM landing gear load

SLA structure for LM attachment

LM descent stage structure - outriggers, beams

Subsystem life

LM descent propulsion

LM ascent propulsion

SM propulsion

CM return payload weight and volume

Saturn V injection weight

According to the previous spacecraft and propellant estimates in Section 2.3 and Appendix C (CONFIDENTIAL) the most obvious required improvement concerns ALM descent propulsion. The potential sources are ascent weight and ΔV, and descent weight and ΔV (assuming propulsion uprating is to be avoided). These first ALM estimates were based on Apollo control weights and a descent ΔV of 7332 fps from the LM Reference Mission. Current data indicate these figures are conservative for the LM. For example, MSC Internal Note No. 66-EG-10, Preliminary LM Powered Descent Trajectory for Flight AS-504A reports a descent ΔV of 7046 fps. (The budget and allowance from the note are shown in Tables I and II).

Also, LM weights reported in the Grumman Mass Property Report, March 1966, are below the LM control weights as follows:

	Control Wt.	Reported Wt.	Δ Wt.
Ascent stage	4835	4639	-196
Descent stage	4775	4746	-29

TABLE I. - FUEL BUDGET (ΔV REQUIRED)

Mission Phase	Design Reference	Flexibility		Contingency	
		Mean	3σ		
Hohmann Transfer	97	13	--	--	
Braking	5362	15	(20)	--	
Final Approach	672	33	(33)	--	
Landing	450	240	(180)	30	
Totals	6581	301	(134)	30	7046

TABLE II. FUEL BUDGET FLEXIBILITY & CONTINGENCY ALLOWANCES

MEAN FLEXIBILITY

Hohmann Transfer	- Orbit Altitude Change (10 n.m., 13 fps)
Braking	- Orbit Altitude Change (10 n.m., 15 fps)
Final Appraoch	- Redesignation Capability (2,000 ft., 33 fps)
Landing	- Radar Uncertainties (15 sec null forward velocity, 80 fps)
	- Detail Assessment Time (30 sec., 160 fps)

3σ FLEXIBILITY

Hohmann Transfer	- No Allowance
Braking	- Thrust Dispersions (2%, 20 fps)
Final Approach	- LPD Uncertainties (Estimated same as redesignation allowance, 33 fps)
Landing	- Variation of Control Technique (80 fps)
	- Radar Uncertainties (slow descent rate, 100 fps)

CONTINGENCY

Landing	- Fuel Depletion Margin (30 fps)

The changes in required descent propellant, using the reported LM weight instead of the control weight and using 7046 fps instead of 7332 fps, are shown below. The maximum usable descent propellant is 17360 lb., which is sufficient for several cases in the example; and almost sufficient for the 500/500 case (17380 lb.).

Descent Payload	Ascent Payload	Landed Weight	Descent Propellant	Separation Weight	Revised Landed Weight	Revised Descent Propellant	Revised Separation Weight
250	80	16006	18175	34331	15592	16680	32422
250	250	16170	18360	34680	15756	16850	32756
250	500	16411	18631	35192	15997	17120	33267
500	80	16256	18456	34862	15842	16950	32942
500	250	16420	18641	35211	16006	17120	33276
500	500	16661	18912	35723	16247	17380	33777
1000	80	16756	19019	35925	16342	17500	33992
1000	250	16920	19204	36274	16506	17650	34306
1000	500	17161	19475	36786	16747	17900	34797

At present it appears that LM weight reductions and changes in the ΔV budgets will be sufficient for the ALM approach. This past example is encouraging for the following reasons:

1) The ALM weight estimate is felt to be conservative, allowing 971 lb. growth in descent stage weight for a nominal staytime of 7 days,

2) The payloads are reasonable increases over the Apollo payloads,

3) Recent Apollo LM weights have been reduced - sufficiently so, that the control weight is expected to be reduced; and

4) The reduced ΔV budget in the example was based on a nominal Apollo descent profile with contingencies and flexibility. Greater improvements in descent capability could result from significant departures from the Apollo descent and ascent profiles.

Data from the Grumman Mass Property Report, March 1966, are shown in Figure 2, Apollo LM Allowable Stage Weight Apportionment. The allowable separation weight and allowable ascent weight are shown in Figures 3 and 4 as a function of ΔV requirements.

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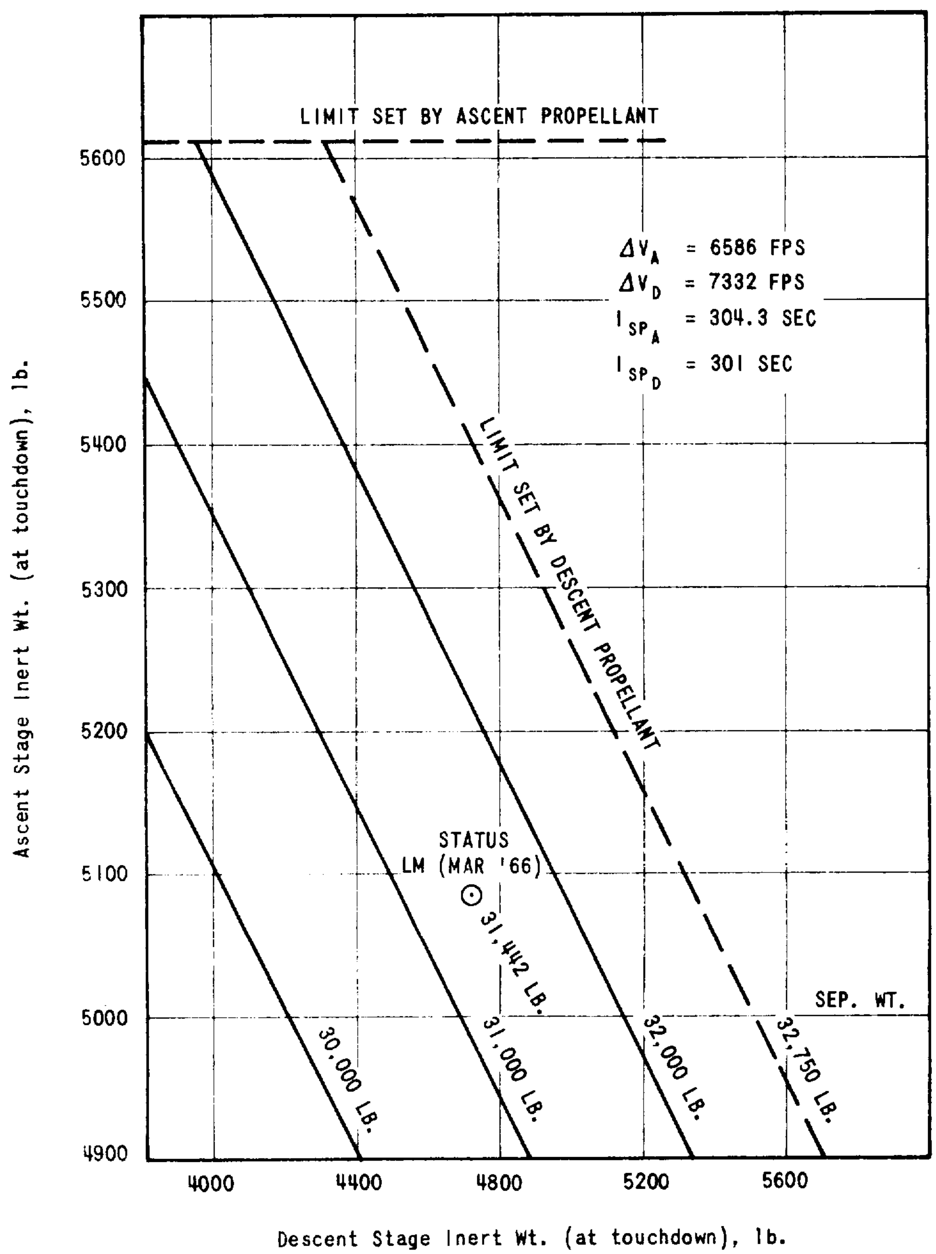

FIGURE 2 - APOLLO LM ALLOWABLE STAGE WT. APPORTIONMENT
(FROM LM MASS PROPERTY REPORT, LED-490-30,
1 MARCH 1966)

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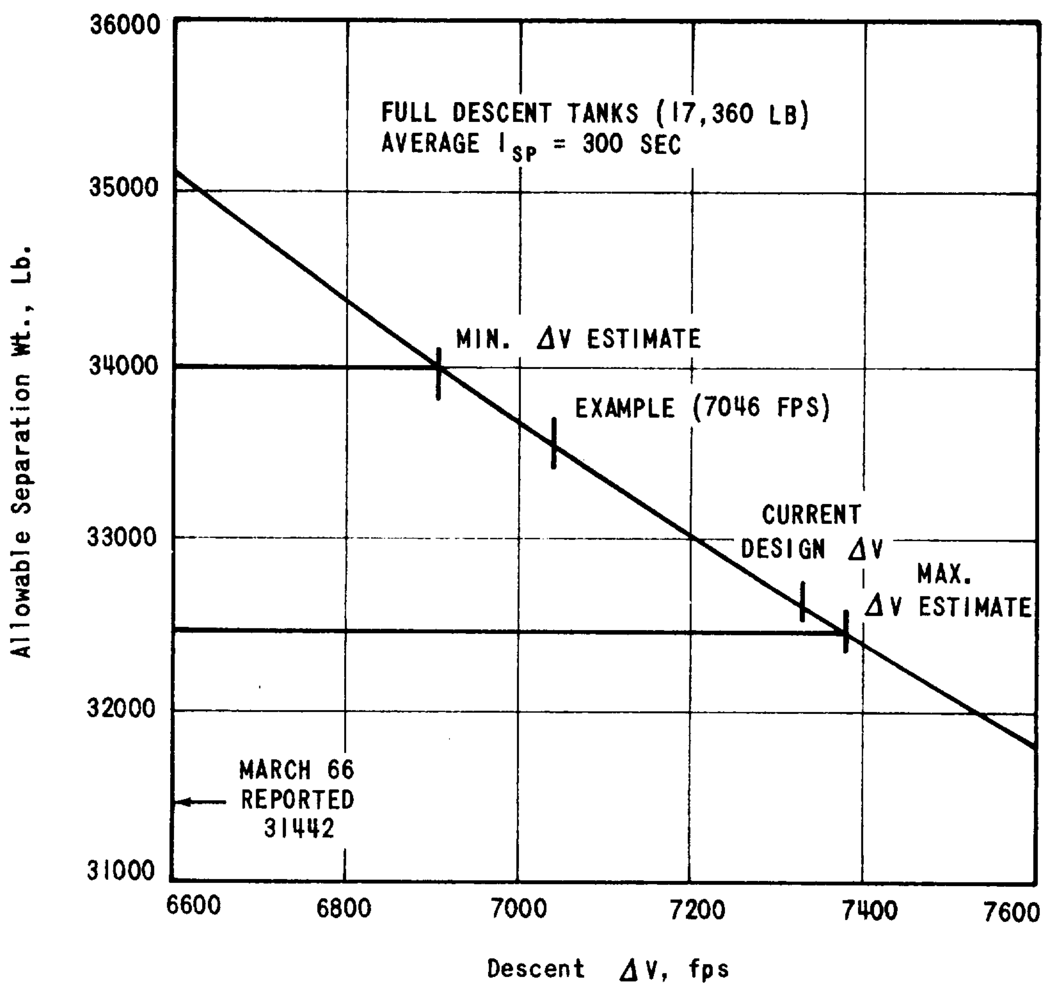

FIGURE 3 - ALLOWABLE SEPARATION WT.

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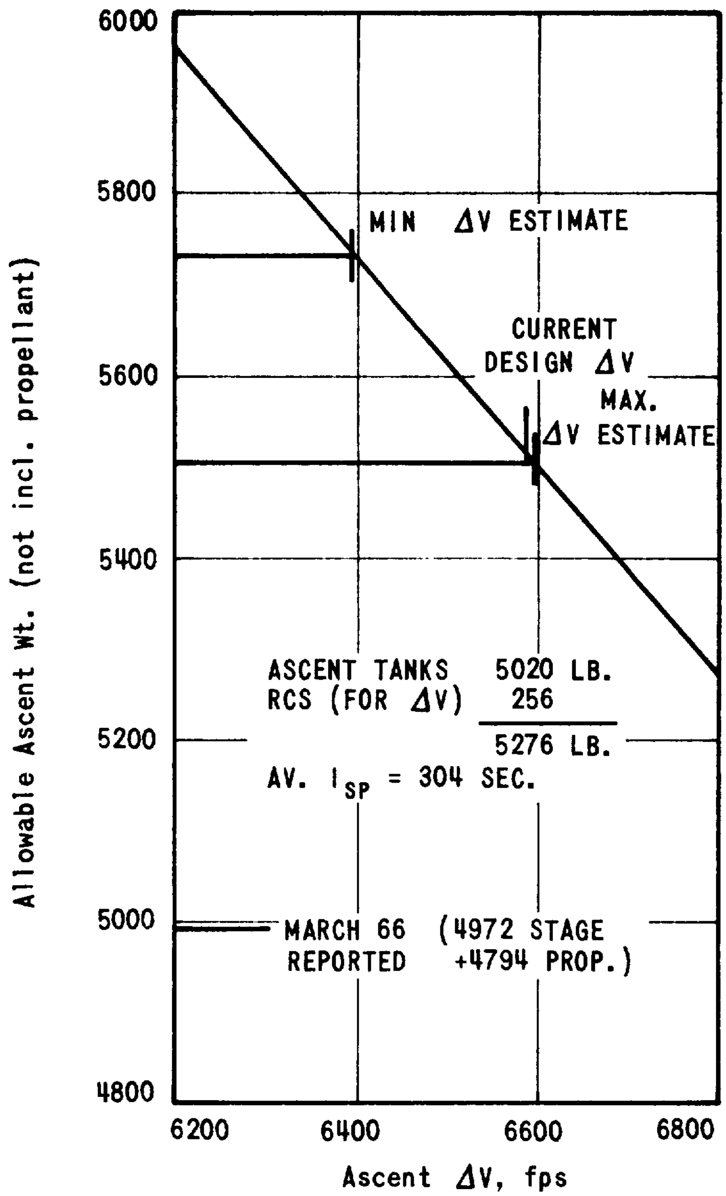

FIGURE 4 - ALLOWABLE ASCENT WT.

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3.0 COMPARISON OF AUGMENTED LM AND SHELTER/TAXI APPROACHES

It is emphasized that the following arguments and considerations are limited to the currently accepted Shelter/Taxi approach which, though relatively well defined, suffers in some cases because of past AAP groundrules and guidelines. Rather than introduce a new set of variables, the following discussion attempts to stress the inherent differences that may determine the potential of the approaches for AAP.

3.1 Staytime

1. The ALM provides a nominal staytime of 7 days for a single Saturn V launch. The Shelter/Taxi pair provides a nominal staytime of 14 days for two Saturn V launches. The difference appears to be 14 days at two sites vs 14 days at one site. If staytime is the prime consideration then the nominal 7-day staytime of the ALM can probably be increased. The Taxi quiescent storage has been limited to 14 days for AAP studies. The penalties for extending this period have not been estimated.

2. The ALM primary power is from solar cells. This limits the ALM to all-day missions. The Shelter/Taxi pair is capable of day and/or night missions.

3. CSM mission duration varies with surface staytime. The nominal ALM 7-day staytime requires a CSM mission duration of 16.7 days. The Shelter delivery mission is nominal Apollo or shorter. The Taxi 14-day staytime requires a CSM mission duration of 23.7 days.

4. Shelter/Taxi missions of 14 days are for day and/or night conditions. Sun angle requirements for Taxi descent and landing or ascent may reduce the useful period to less than 14 days.

5. LM Taxi staytime in the event of Shelter failure is one day.

3.2 Payload to Surface

1. Shelter payload is 3,000 to 3,500 lbs. The Taxi is assumed to have no useful scientific payload. ALM payload is not defined, but would probably be between 500 and 1000 lbs.

2. ALM storage volume is severely limited compared to the Shelter. If the ascent stage weight is held to the Apollo control weight for abort during the landing, then essentially all of the delivered payload (and the heavier modifications) must be on the descent stage. In addition, the volumes available appear to be irregular and unsuitable for single, larger payloads such as roving vehicles.

3. The hard suit, presently ground-ruled into the Shelter payload, is tailored to fit a specific crew member. It may be unsuitable to commit a Shelter/Taxi mission to a specific crew well in advance of crew launch.

4. If it were planned to revisit a site, the equipment on the first mission could be planned for reuse or combination. Question: is this more suitable for ALM or Shelter/Taxi? The ALM is more payload limited and committing a second ALM Saturn V launch to a single site appears more reasonable than a third and fourth for a repeat Shelter/Taxi mission to a single site.

3.3 Return Payload

The Taxi return payload is 250 lb. The ALM return payload is 500 lb. Two ALM missions return 1000 lb. as opposed to the Shelter/Taxi mission return of 250 lb. If the Taxi is assumed to have the same return payload as the ALM, then the ALM still returns twice as much per Saturn V.

Block II CSM return payload capability is 161 lb. in a storage volume of 2.72 cu. ft. With modification, this can be increased to approximately 400 lbs. and 14.52 cu. ft.*

---

*Apollo Applications Payload Planner's Handbook - Alternate Apollo Missions, North American Aviation, January 31, 1966.

3.4 Mission Success

Shelter/Taxi mission success should be lower than the Augmented LM mission because of the following:

1. Two Saturn V launches.
2. Taxi launch constrained by Shelter site.
3. Unmanned landing of Shelter.
4. Shutdown, storage, and remote activation of Shelter.
5. Shutdown, quiescent storage, and activation of Taxi.
6. Abort reactivation of Taxi.
7. Mission duration of Shelter, Taxi, and CSM escort for Taxi.
8. Storage of Shelter payload.

3.5 Crew Safety

Shelter/Taxi crew safety should be lower because of items 5, 6, and 7 above.

3.6 Accessibility

1. The Shelter/Taxi launches apply constraints, mutually, on site and launch windows that do not apply to the ALM launch.

2. ALM mission durations permit better accessibility with anytime abort for a given plane change capability.

3. Two ALM missions allow two sites.

The significant differences in lunar accessibility for the two approaches arise from Shelter/Taxi dual launch, different staytimes, and anytime abort considerations.

Committing the Taxi launch to a Shelter site requires a compromise, as yet unestimated, between mission accessibility and Taxi launch windows.

Site and staytime are related by plane change capability of both spacecraft for the rendezvous and by CSM plane change for transearth injection, which is related to staytime in orbit following rendezvous.

In general, it appears a 7-day staytime permit about five times the latitude accessibility of a 14-day staytime for an anytime abort surface mission. (See Figure 5). If abort requirements are relaxed, the 14-day staytime accessibility increases to the poles in a 15 to 20 degree band at approximately ±90 degrees longitude. 7-day accessibility is essentially unchanged for the abort-no abort cases.*

3.7 <u>LM Modifications</u>

1. The nature of the missions dictates the type of modifications. The ALM is an extension of the current LM, and the mission is similar to the LM mission. Capabilities are of the same type; and improvements result from add-ons, a matter of weight, rather than more sophisticated and lighter modifications.

The Shelter and Taxi requirements differ from those of the LM (and ALM). The Taxi must provide LM-type descent and ascent, plus quiescent storage during the surface stay. The Shelter must provide unmanned landing, deactivation, quiescent storage, reactivation (including fuel cell startup), and extended crew and experiment support.

2. The Shelter/Taxi approach requires changes that should be made during production at Grumman. The ALM can be modified post-production at KSC or Grumman. AAP schedule M(P)-2/A shows the 512/513 mission using LM 13 and LM 14 after conversion. If this holds, the minimum modification ALM approach would be more suitable than the Shelter/Taxi.

3. The Shelter/Taxi approach requires two distinctly different LM derivatives to be designed and tested in limited numbers. The ALM approach requires a single derivative of less extensive modification.

4. The major changes in the ALM are in environmental control, largely the addition of LM oxygen and water tanks; and in electrical power, the addition of a solar cell array.

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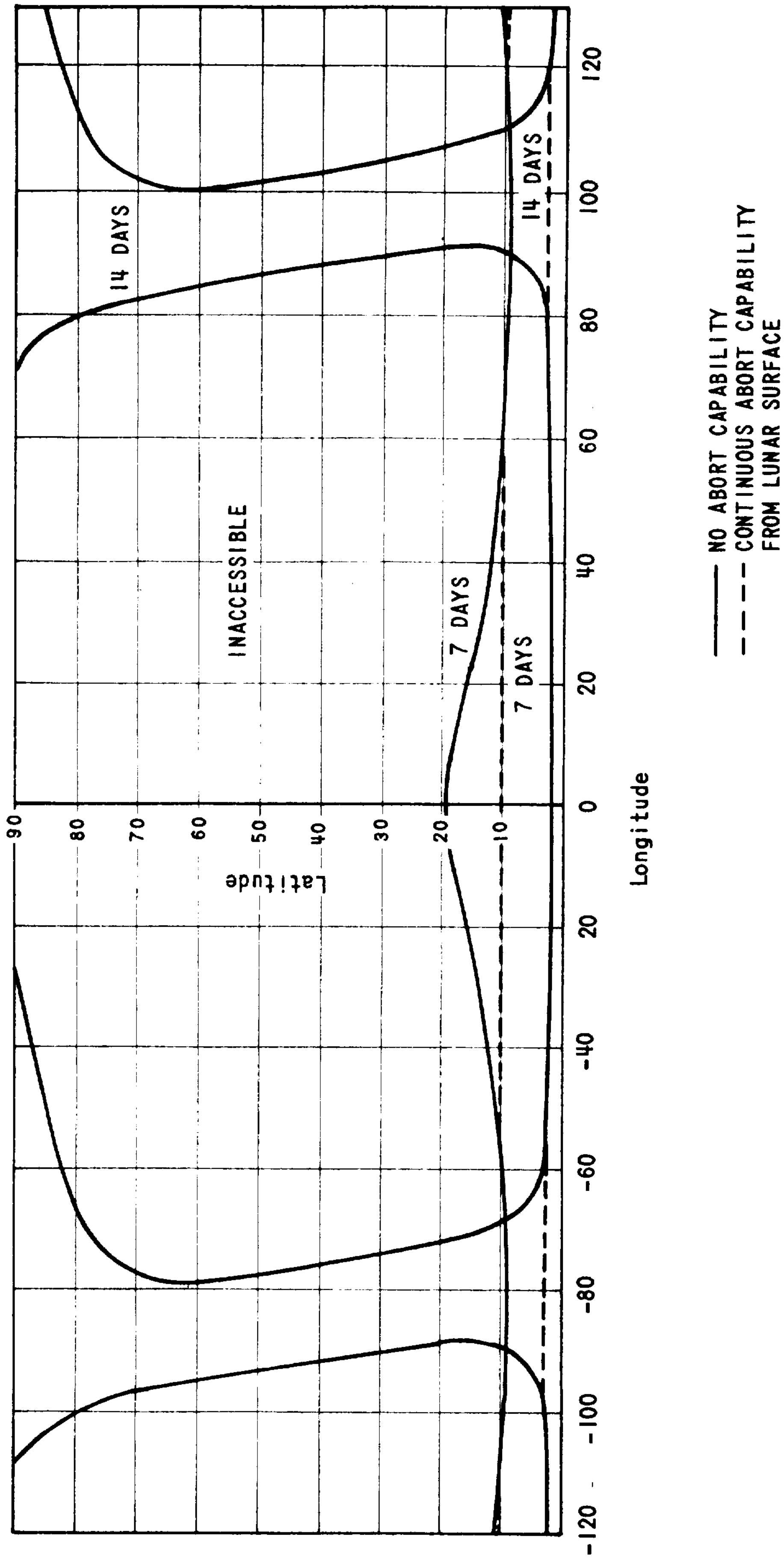
*P. W. Conrad, Working Papers, Comparison of Augmented LM Mission vs the Shelter/Taxi Mission from the Point of View of Surface Accessibility, August 26, 1966.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60
80
100
120
-20
-40
-60
-80
-100
-120
——— NO ABORT CAPABILITY
– – – CONTINUOUS ABORT CAPABILITY FROM LUNAR SURFACE

FIGURE 5

Development risk for the Shelter/Taxi appears to be higher because of unmanned landing and storage requirements, use of AAP fuel cells and cryogenic storage (development as GFE is not assured), development of suitable payloads (e.g., LSSM), and several lesser efforts involved, such as antenna relocation and a scanner for the S-Band antenna.

3.8 CSM Modifications

1. On the basis of mission duration alone, the ALM appears to have minimum impact on the CSM. Modifications appear to be only for additional expendables, as a function of increased lunar orbit time. This assumes the SPS capability is not exceeded by either approach and that total CSM mission times are comparable in terms of hardware life (e.g., fuel cells). Maximum CSM mission times are 16.7 days for the 7-day ALM and 23.7 days for the 14-day Taxi.

2. A Shelter/Taxi mission requires one Block II CSM and one 23.7-day CSM. Two ALM missions require two 16.7-day CSM's. We have the Block II CSM, and the 16.7 day CSM appears to be a minor modification of the Block II. Modification to the CSM to obtain a 23.7-day capability have not been determined.

3.9 Augmented Shelter/Taxi

Providing the Shelter/Taxi with uprated descent propulsion would provide additional weight capability for increasing staytime and scientific payload. This weight increase would require descent stage and landing gear structural modifications. Mission success and crew safety items previously mentioned would still apply, though some of the hardware-related items might be improved with additional weight. It appears, however, that return payload would not be improved significantly over that provided by the ALM approach.

3.10 Electrical Power

1. The ALM solar cell approach is more limited in providing for lunar drills and other heavy power equipment.

2. The Shelter might benefit from solar cells if the Taxi mission were restricted to a lunar day mission.

3.11 Lunar Environment

The Shelter and Taxi durations of exposure to the lunar radiation and micrometeoroid environment are significantly longer than that of the ALM.

3.12 Growth

Neither approach provides for significant growth within the present derivatives. If a LM Truck is introduced both approaches can be improved by additional payload for staytime, shelter, and mobility. This effectively removes the descent payload advantage of the Shelter/Taxi and the single launch-related advantages of the ALM. Truck support for staytime extension remains as a consideration. It appears that both the Taxi and the ALM would benefit. The upper limit appears to be affected most by CSM lunar orbit duration, LM hardware common to both approaches (e.g., ascent propellant temperatures), and the ability of the ALM and Taxi to withstand day and night conditions. The ALM solar cell approach would not permit night missions.

4.0 SUMMARY AND CONCLUSIONS

An ALM approach based on minimum modification appears feasible.

The ALM weight increase for a 7-day staytime is estimated to be 971 lb in the descent stage and 34 lb in the ascent stage, using additional LM hardware for expendables and a solar cell panel for electrical power.

CSM Block II subsystems are assumed to be suitable for an ALM mission duration having an upper bound of 16.7 days. The expendables and tankage increase for this mission are estimated to be 587 lb.

Ascent stage and SM propellant quantities and the current Saturn V injected weight appear to be adequate, based on the Apollo control weights and ΔV budget. However, on this basis, the requirements exceed descent propulsion capability in all cases. Current data indicate the control weights and the descent ΔV used are conservative. In the example given, it is shown that if the current LM weight reported by Grumman and a recent descent ΔV estimate are used, the maximum descent propellant is found to be sufficient for ALM payloads of approximately 500 lb descent and 500 lb return.

The increased capability of the ALM is primarily a weight consideration for increased staytime, descent payload, and ascent payload. There are several sources for necessary improvements; however, there are specific limitations to these potential improvements for a minimum modification approach. Further study is recommended in estimating reasonable bounds on anticipated ΔV requirements, projected launch vehicle and spacecraft propulsion capability, and specific structural limitations of the SLA/LM interface, CM chute, CM return payload, LM landing gear, and LM descent stage structure.

<u>Comparison with Shelter/Taxi Approach</u>

Both approaches have advantages related, basically, to the Shelter's greater staytime, descent payload, and payload volume and the ALM's relative simplicity, single Saturn V launch, and return payload.

The Shelter/Taxi staytime is greater, a nominal 14 days <u>vs</u> 7 days; but the ALM provides 14 days at two sites for two Saturn V launches.

The ALM mission duration of 16.7 days has less impact on the CSM than the Taxi mission of 23.7 days.

Shelter surface payload is 3000 to 3500 lb; the ALM surface payload is 500 lb, or 1000 lb for two Saturn V launches.

The ALM return payload is 500 lb, or 1000 lb for two Saturn V launches. Taxi return payload is 250 lb. If the Taxi return payload is assumed to be 500 lb, the ALM returns twice as much per Saturn V.

Shelter payload volume is better than the ALM, and permits a 1500 lb roving vehicle payload.

ALM mission success and crew safety appear to be higher.

ALM accessibility is greater with provision for anytime abort. If the abort constraint is relaxed, ALM accessibility increases in the region near 0° longitude and Shelter/Taxi accessibility increases near ±90° longitude.

ALM modifications are simpler and could be made post-production at KSC or Grumman. The Shelter/Taxi Approach requires changes that should be made during production at Grumman. ALM development appears to involve fewer long lead time items, lower development risk, and a reduced near-term NASA commitment.

1013-JEW-rpk J. E. Waldo

APPENDIX A

AUGMENTED LM WEIGHT ESTIMATE

A1. Assumptions

- 7-day staytime
- Minimum modifications - simple add-ons to existing LM subsystems
  - modify subsystems for clear weight advantage only
- Nominal Apollo mission profile
- Apollo LM subsystems are suitable for 7-day staytime
- Electrical energy based on Apollo power levels
- Two EVA per day

A2. LM Changes and ΔWeights

	Δ Ascent Stage	Δ Descent Stage
Essentially no changes in S&C, N&G, Landing Gear*, RCS*, & Communic.	-	-
Minor changes in		
Structure	+34	-
-Increase micrometeoroid shielding, 34 lb		
-Change supports for tankage & equipment		
Crew Provisions		+91
-Add food, 30 lb		
-Add 6 PLSS LiOH, 21 lb		
-Add 8 PLSS batteries, 40 lb		
Instrumentation and Controls & Displays	-	-
-Change EPS & ECS		
Major changes		
Environmental Control (except thermal control)	-	+452
-Add 7 LiOH, 53 lb		
-Add oxygen & tankage, 178 lb		
-Add water for crew & EVA, 221 lb		
-Increase thermal control (**)		
Electrical Power	(**)	(**)
-Increase total energy		

*Possible changes based on early landings, but no weight increase.
**Thermal control and electrical power are estimated separately.

A2.1 Environmental Control

Thermal Load		
Environment	740	Btu/hr average
Crew	1000	"
Electrical(0.72 KW)	2450	"
	4190	Btu/hr

The weights for two thermal control approaches are given below.

APPROACH	ASCENT STAGE	DESCENT STAGE	Δ ASCENT	Δ DESCENT	Δ SEPA-RATION WEIGHT
A. Water	-	water 704, tanks 48 = 752	0	+466	+892
B. Radiator & Water	Mod. glycol system 94	radiator 76, water + tank 190 = 266	+94	- 40	+296

A2.2 Electrical Power

-Determine energy requirements from Apollo
-Consider battery, fuel cell, solar cell approaches*

Energy Requirements (Apollo power levels):	A/S (KWH)	D/S (KWH)
Countdown	-	0.8
Translunar (11 KWH from CSM)	0.4	2.0
Separation to Touchdown	-	3.39
Post landing checkout	0.34	1.34
Surface (7 days at 0.722 KW)	-	121
Prelaunch	0.74	1.73
Ascent, incl. 9 hr. contingency	14.2	-
TOTAL	16 KWH	130 KWH

*RTG not considered because of weight and no requirement for waste heat.

EPS Approaches:

-Batteries	
AgZn(LM), 130 KWH	1560 lb
ZnO, ($\sim\frac{2}{3}$ AgZn), 130 KWH	1040
-Fuel Cells	
2 A-C fuel cells plus accessories	420
Radiator (55 sq ft vertical)	80
(Reactants incl. fuel cell parasitic load)	283
-Solar Cell Array	
1100 watt, 162 ft^2	260

EPS WEIGHT SUMMARY

	ASCENT STAGE	DESCENT STAGE	Δ ASCENT	Δ DESCENT	Δ SEPARATION WEIGHT *
CURRENT LM	batteries 261	batteries 556	0	0	0
A. All battery AgZn	batteries 261	batteries 1560	0	+1004	+2008
B. All battery ZnO	batteries 261	batteries 1040	0	+ 484	+ 968
C. Fuel Cells in D/S	batteries 261	fuel cells 420 radiator 80 reactants 283 water -115 668	0	+ 112	+ 224
D. Fuel Cells in A/S	fuel cells 420 radiators 80 reactants 58 rech.batt. 56 614	reactants 283 water -115 168	+343	- 388	+ 596
E. Solar Cell Array	batteries 261	solar array 260 batteries(2) 278 538	0	- 18	- 36

*Based on 2 x D/S inert and 4 x A/S inert

[illegible] WEIGHT SUMMARY

The following table gives the total inert weight change for the ascent and descent stages and an approximate separation weight change, which includes propellants. The ECS thermal control cases are add-on (additional water) and modified (add radiator to glycol loop). The EPS cases are add-on (add solar cell array, EPS case E) and modified (fuel cells in descent stage, EPS case C). Separation weight is estimated as 2xD/S inert and 4xA/S inert.

		Δ ASCENT	Δ DESCENT	Δ SEPARATION WT.
ADD-ON ECS	ADD-ON EPS	+34	+971	+2078
MOD. ECS	ADD-ON EPS	+128	+485	+1482
ADD-ON ECS	MOD. EPS	+34	+1101	+2338
MOD ECS	MOD EPS	+128	+615	+1742

APPENDIX B

CSM WEIGHT ESTIMATE

B1. Assumptions

- 7-day ALM staytime
- Minimum modifications
  - simple add-ons to existing CSM subsystems.
  - modify subsystems for clear weight advantage only.
- Nominal Apollo mission profile except for increased lunar orbit time.
- CSM subsystems are suitable for mission duration.

B2. Mission Duration

The major variables are translunar coast, CSM solo operations, and transearth coast times. Assuming other time values are constant (shown as "other", from DRM-1) the range of mission phase times are as shown below.

	Translunar	CSM solo ops.	Trans-earth	Other	Total
DRM-1	61.15	37.49	88.95	10.96	198.55 hr (8.3 d)
7-day ALM Lower bound	86	170	86	11	352 hr (14.7 days)
7-day ALM* Upper bound	110	170	110	11	400 hr (16.7 days)

B3. Expendables

For expendables, use CDR data based on DRM-1 modified for increased translunar, lunar orbit, and transearth times.** Assume upper bound on total mission time of 400 hours (16.7 days). Expendables exception: because of present indecision on suitability of RCS quantities, assume propellants are sufficient for Apollo and increased requirements will exceed present RCS tankage.

*Longer translunar and transearth times reduce ΔV requirements and reentry velocity. The latter may be important for heat shield considerations on the heavier CM.

**AP 65-65 NASA/NAA Critical Design Review Number 3 Phase II Appendix V to SID-65-1480, December 1965, North American Aviation

B3.1. RCS

Total usable is 790 lb. Assume Apollo requires 790 lb., including 286 lb. for contingencies.* Estimate expected and minimum values.

Additional required for increased orbit time of 133 hours, approximately 67 orbits, using minimum values from TRW study**.

SCS attitude hold at ±4.2 degrees	
133 hours at 0.07 lb/hr	9.3 lb
1 roll maneuver per orbit	
67 orbits at 0.1 lb/maneuver	6.7 lb

Total RCS propellant increase is 17 lb. This is 2% of the total usable and is 6% of the contingency reserve. If the assumption that Apollo requires all of the total usable is valid, then it may be possible in later missions to find 17 lb. on the basis of confidence. If Apollo requires larger tanks, then 17 lb. is not a problem.

Note that the 17 lb. represents a minimum increase.

A second estimate, based on LM Taxi Escort mission***.

Translunar	198.8
Orbital with LM	48.9
Orbital without LM (1-quad-out)	244.
CSM rendezvous	123.9
MSFN fail	72.0
Transearth	184.9
TOTAL	858 lb

Total RCS propellant increase is 68 lb.

*AP 65-65 NASA/NAA Critical Design Review Number 3 Phase II Appendix V to SID-65-1480, December 1965, North American Aviation
**J.J. O'Connor, SM RCS Briefing Charts, May 17, 1966.
***SID 65-1528 Table 22.

Note that the requirements by phase shown above include penalties for 1-quad-out and MSFN failure. For determining SPS requirements for transearth injection must assume the mission has been nominal and that minimum amount of RCS propellant has been used, yielding greater weight for TEI.

From CDR, have the following values:

Translunar	177
Lunar Orbit	152
Minimum increase	17
TOTAL	346 lb

Maximum remaining RCS at TEI is 444 lb.

B3.2 Environmental Control

Requirements are based on a total mission time of 400 hours; 170 hours with one crew member and 230 hours with three crew members.

Oxygen-repressurizations and leakage rates are assumed to be Apollo.

Crew Consumption	
230 hours, 3 crew members, at 0.08 lb per man-hour	55.1 lb
17 hours, 1 crew member, at 0.08 lb per man-hour	13.6
Leakage - 400 hours at 0.2 lb/hr	80
LEM pressurization - 1 at 7 lb	7
CM repressurization - 1 at 7 lb	7
TOTAL ECS OXYGEN	162.7 lb

LiOH - Assume one charge is sufficient for three men for 12 hours, based on 2.12 lb CO_2 per man-day. 860 man-hours requires 24 cartridges; Apollo carries 28, which is sufficient.

Food - Assume 1.3 lb/man-day for 35.8 man-days; therefore need 46.5 lb. Apollo carries 45 lb and has capacity for 80 lb.

Water -

Crew uses 10.2 lb/man-day (all but 3.34 lb/man-day is recovered) for 35.8 man-days	365 lb
Thermal control (radiator supplement) in lunar orbit with one crew requires 0 to 0.2 lb/hr	34 lb
Total, crew use and lunar orbit thermal control	399 lb

B3.3 Electrical Power -

Assume Apollo power profile and 400 hour mission for sizing reactants.

Additional requirements for increased mission times:

Translunar coast	1877 w for 49 hours	97 KWH
Lunar orbit	2079 w for 133 hours	277
Transearth coast	1977 w for 21 hours	41.5
TOTAL		415.5 KWH
Oxygen required at 0.68 lb/KWH		283 lb
Hydrogen required at 0.085 lb/KWH		35.3 lb

Total oxygen and hydrogen for 400 hour mission:

Oxygen (lb)	DRM-1	Add'l	400 hr
Electrical power	346	283	629
Purges	2	2	4
Crew (ECS)	42	27	69
Leakage (ECS)	40	40	80
Miscellaneous	11	3	14
Reserve*	-	-	96
TOTAL			892 lb.

*Based on 8 times Apollo hydrogen reserve.

Hydrogen (lb)

Electrical power	43	35.5	78.3
Purge	1	1	2
Reserve	12	0	12
TOTAL			92.3 lb

Water produced (sum of 629 lb Oxygen and 78.3 lb hydrogen) is 707 lb (see ECS)

B4. CSM Weight Summary

	Block II Usable	400 hr Required	Add'l Required	Add'l Tankage	Total Add'l Weight
RCS	790	858	68	-	68
Oxygen	655	892	237	82	319
Hydrogen	56	92.3	36.3	164	200
Food & LiOH					neglig.
Total weight increase					587 lb

[redacted]

APPENDIX C

ALM SPACECRAFT AND PROPELLANT WEIGHTS

This appendix contains a first estimate of the ALM and associated CSM weights for a mission that provides an ALM staytime of 7 days. These estimates are based on Apollo Control Weights, Apollo ΔV requirements, ALM and CSM Δ inert weights estimated in Appendices A and B, and various combinations of descent and return payloads.

[redacted]

APPENDIX C

ALM SPACECRAFT AND PROPELLANT WEIGHTS

This appendix contains a first estimate of the ALM and associated CSM weights for a mission that provides an ALM staytime of 7 days. These estimates are based on Apollo Control Weights, Apollo ΔV requirements, ALM and CSM Δ inert weights estimated in Appendices A and B, and various combinations of descent and return payloads.

APPENDIX C

ALM SPACECRAFT AND PROPELLANT WEIGHTS

C1. SPACECRAFT WEIGHTS

The weights used are the Apollo Control weights, Augmented LM increased inert weights, and various descent and return payloads.

Control Weights - The following weights, from the Apollo Program Specification, are reduced by the Apollo descent payload:

CM	11,000 lb	(less 80 lb)	10,920 lb
SM	10,200		10,200
LMA/S	4,835		4,835
LMD/S	4,775	(less 170 lb)	4,605
SLA	3,800		3,800

Δ Inert Weights - Calculated spacecraft increased inert weights are:

CSM	+590 lb
LM A/S	+ 34 lb
LM D/S	+971 lb

Payloads - The range of descent and return payloads are:

Descent:	250, 500, and 1,000 lb.
Return:	80, 250, and 500 lb.

C2. PROPELLANT WEIGHTS

Maximum Usable Propellant Weights - The following weights are from the Apollo Program Specification:

SM	39,720 lb*	
LM A/S	5,276	(includes 256 lb RCS)
LM D/S	17,360	

Propellant Requirements - The following propellant weights and mass ratios are from CDR, December 1965, based on DRM-1 (for SM propellants) and from LM Mass Property Report, March 1966 (for LM propellants):

SM Translunar Midcourse Correction	2,671 lb propellant
SM Lunar Orbit Insertion	0.412 lb propellant/lb. inert
SM Transearth Injection	0.314 lb propellant/lb. inert
LM D/S Descent	1.125 lb propellant/lb. inert
LM A/S Ascent	0.965 lb propellant/lb. inert

*41,000 lb in Apollo Program Specification is to be revised.

[redacted]

C3. WEIGHT SENSITIVITIES

The following changes in propellants and weights for given changes in inert and payload weights are based on the mass ratios shown under Propellant Requirements.

	CSM Inert	LM A/S Inert	LM D/S Inert	Descent Payload	Ascent Payload
SM Propellant	0.854	1.721	0.875	0.875	1.289
LM D/S Propellant	-	2.117	1.125	1.125	1.086
LM A/S Propellant	-	0.965	-	-	0.965
SM Separation Weight	-	4.082	2.125	2.125	2.051
Total Injected "	1.855	5.803	3.000	3.000	3.340

C4. BASELINE CASE

The following table shows the spacecraft inert and payload weights by phase for Apollo descent and return payloads of 250 and 80 lbs and increased inert weights of 590 lbs for the CSM, 34 lb for the LM A/S, and 971 lb for the LM D/S:

[redacted]

Spacecraft Inert Weights - Baseline Case, for Apollo control weights and payloads.

[redacted]

	CSM	LM ASCENT STAGE	LM DESCENT STAGE	
Apollo Launch and TLI	21120	4835	4605	note A.
Δ Inert	+[590]	+[34]	+[971]	note B.
Descent Payload	-	-	+[250]	
Launch and TLI	21710	4869	5826	
RCS	-177	—	—	
ECS	- 49.5	—	—	
EPS	-197	—	—	
Crew & Equip.	—	—	—	
TOTAL	-424	—	—	
Lunar Orbit Insertion	21286	4869	5826	
RCS	—	-4.4	—	
ECS	—	—	-16.2	
EPS	—	—	—	
Crew & Equip	-537.4	+537.4	—	
TOTAL	-537	+533	-16	note C.
Separation and Descent	20749	5402	5810	
RCS	—	-165.6	—	note D.
ECS	—	—	- 9.9	
EPS	—	—	—	
Crew & Equip.	—	—	—	
TOTAL	—	-166	-10	
Lunar Touchdown	20749	5236	5800	
RCS	-169	-4.4		
ECS	-61.6	—		
EPS	-320	—		
Crew & Equip.	—	-108.9		
TOTAL	-551	-113		
Return Payload	—	+[80]		
Ascent	20198	5203		
RCS	—	-56.6	note D.	
ECS	—	-12.3		
EPS	—	—		
Crew & Equip.	+532.7	-532.7		
TOTAL	+533	-602		
Return Payload	+[80]	-[80]		
Transearth Injection	20811			

A. Apollo control weights, less descent payload (80 lb. CSM, 170 lb. LM D/S).
B. Calculated for 16.7 day CSM mission and 7 day LM surface mission.
C. From LM Mass Property Report, March 1, 1966.
D. LM RCS also used for ΔV (19.7 descent, 256 lb. ascent).

[redacted]

SUMMARY TABLE

Based on Apollo control weights plus increased inert weights of 590 lb. for the CSM, 34 lb. for the LM A/S, and 971 lb. for the LM D/S.

[redacted]

PAYLOADS		SPACECRAFT INERT WEIGHT			PROPELLANTS			ALM	ALM	Total
Descent	Return	CSM	LM A/S	LM D/S*	SM**	LM A/S	LM D/S	Landed Weight	Separation Weight	Injected Weight***
250	80	21710	4869	5826	35602	4944	18175	16006	34331	94926
250	250	21710	4869	5826	35821	5108	18360	16170	34680	95494
250	500	21710	4869	5826	36143	5349	18631	16411	35192	96329
500	80	21710	4869	6076	35821	4944	18456	16256	34862	95676
500	250	21710	4869	6076	36040	5108	18641	16420	35211	96244
500	500	21710	4869	6076	36362	5349	18912	16661	35723	97079
1000	80	21710	4869	6576	36258	4944	19019	16756	35925	97176
1000	250	21710	4869	6576	36477	5108	19204	16920	36274	97744
1000	500	21710	4869	6576	36799	5349	19475	17161	36786	98579
Current maximum usable values					39720	5276	17360		-	98000

*Includes Descent Payload

**Does NOT Include Reserve Propellant

***Includes SLA (3800 lb.)

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